Combined Gamma-Ray Spectrometer and Pulsed Neutron Generator System for In-Situ Planetary Geochemical Analysis.

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Introduction: A combined pulsed neutron/gamma-ray system can be used on planetary surfaces to provide valuable geochemical analysis of surface materials to depths of ~1 m. Using pulsed neutron generators enables statistically significant measurements in much shorter times than could be accomplished with galactic cosmic rays. In this work we describe experimental results that demonstrate the capabilities of such a combined system.

Planetary Gamma-Ray and Neutron Measurements: The analysis of characteristic gamma-ray and neutron spectra induced by cosmic-ray interactions in planetary surfaces is a powerful technique for geochemical analysis of surface materials down to depths of ~1 m. Orbital gamma-ray measurements on Apollo 15 and 16, Lunar Prospector, and Mars Odyssey missions have all produced quantitative elemental abundance measurements [1,2,3]. Lunar Prospector and Mars Odyssey also carried neutron spectrometers that are extremely effective in determining hydrogen (water) abundances [4,5]. Other orbital missions that carry similar instrumentation include the MESSENGER mission to Mercury (gamma ray and neutron) and the Lunar Reconnaissance Orbiter mission (neutron) [6,7].

In situ gamma-ray measurements have been accomplished on Venus (Venera 8-10) and 433 Eros (NEAR) [8,9]. To date there have been no *in situ* neutron measurements on any planetary surface. The first such planned experiment will be accomplished on the Mars Science Laboratory (MSL) scheduled for launch in 2009. The Dynamic Albedo of Neutrons (DAN) instrument will use a pulsed neutron generator (PNG) and two He-3 counters to measure thermal and epithermal neutron fluxes induced by the 14-MeV neutron output of the generator [10]. The MSL instrument payload does not include a gamma-ray spectrometer.

Experimental Setup: Over a period of ~5 days a series of measurements were made at Schlumberger Princeton Technology Center. The basic components of the system were a pulsed neutron generator, a large soil sample and a gamma-ray spectrometer as shown in Figure 1. The geometry was fixed throughout, but water was gradually added to the bottom of the soil container so that the impact of varying the hydrogen content while maintaining a constant soil composition could be evaluated. One measurement also included the addition of PVC slabs near the top of the soil container to determine the effect of increased chlorine content.

The Schlumberger PNG emits 14-MeV neutrons isotropically and can produce pulses with widths and frequencies over a wide range of values. For the results reported here, the pulse width was 200 microseconds and the frequency was 500 Hz. The average neutron output was $\sim 5\times10^{7}$ neutrons/s.

The gamma-ray detector was a 5-cm diameter by 5-cm long LaCl detector with energy resolution of ~4.5% at 662 keV. The detector was surrounded by a thin Cd foil to minimize the interaction of thermal neutrons in the detector.

The soil sample was contained in an ellipsoidal tank that measured approximately 138 cm long by 89 cm wide and 64 cm deep. As explained previously, the soil itself was not changed, but water was added from the bottom and PVC slabs were added near the top of the tank providing 5 different layering configurations:

1. Dry soil (estimated to contain ~2 wt% water).
2. Water level at 25 cm below the top of the tank.
3. Water level at 10 cm below the top of the tank.
4. Water level at the top of the tank.
5. Same as 4, but with PVC slabs.

Measurement Results: Using simple electronic gating techniques, separate spectra are collected with the generator pulse on and with the pulse off. Pulse-on spectra are dominated by inelastic neutron scattering reactions and the pulse-off spectra are primarily the result of thermal neutron capture and activation reactions. Typical spectra collected during a 1-hour period are shown in Figure 2.

The ability to separate the inelastic and capture spectra is an important advantage of using a PNG that is not possible with cosmic ray or radioactive sources. Separating these two reaction types reduces background and greatly enhances the ability to extract peak areas, particularly in the capture spectra.

Impact of varying water level. Measurements on a planetary surface where water abundance may be significant and vary substantially over distances of a few kilometers (e.g. Mars Polar Regions) can complicate the task of extracting geochemical information from gamma-ray spectra. A primary goal of these measurements was to determine the impact of such variations and to see how well modeling can reproduce the measured counting rates

Figure 3 shows how the count rates of the H (2.223 MeV) and the Si (3.539 MeV) capture lines vary with the five different soil configurations. The MCNPX (Monte Carlo N-Particle eXtended) modeling of these lines is also shown and as can be seen, tracks the measurements very well [11]. Because of uncertainties in the PNG output and water content of the dry soil the modeled results were normalized to agree with the H measurement for configuration #4, water filled to the top of the tank. As expected, the count rates for these two thermal neutron capture lines increase as the water level increases; the Si count rate increases even though its concentration (wt%) decreases. The decrease in the count rates when the PVC is added is the result of the high thermal neutron capture cross section of the chlorine, which reduces the number of thermal neutrons available to interact in the soil.

Conclusion: A combined PNG/gamma-ray system has the potential to provide significant geochemical results on planetary surfaces. The ability to separate the inelastic and capture spectra improves the quality of the data, and hence simplifies the data analysis.

References: [1] Metzger A. E. et al. (1973) *Science*, **179**, 800-803. [2] Lawrence D. J. et al. (2002) *J. Geophys. Res.*, **107**, 5130. [3] Boynton W. V. et al. (2004) *Space Sci. Rev.*, **110**, 37. [4] Feldman W. C. et al. (1998) *Science*, **281**, 1496-1500. [5] Feldman W. C. et al. (2002) *Science*, **297**, 75– 78. [6] Gold R. E. et al. (2001) *Planet. Space Sci.*, **49**, 1467-1479. [7] Mitrofanov I. G. et al. (2005) *LPSC XXXVI*, No. 1879. [8] Surkov Y. A. et al. (1977) *LPSC VIII*, 265. [9] Evans L. G. et al. (2001) *Meteoritics and Planetary Science*, **36** 1639-1660. [10] Mitrofanov I. G. et al. (2005) *LPSC XXXVI*, No. 1635. [11] D. Pelowitz (Ed.), MCNPX User's manual, LANL, 2005.

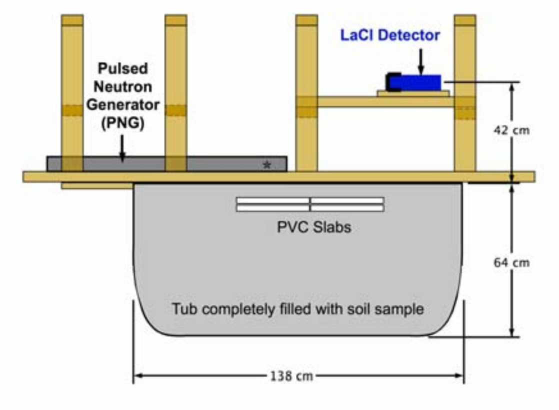

Figure 1. Experimental set-up.

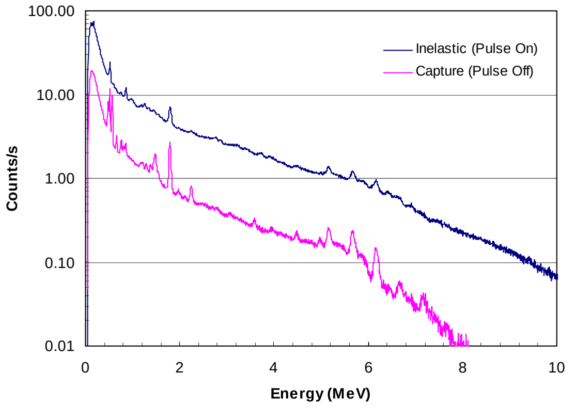

Figure 2. Inelastic (blue) and capture (pink) spectra collected in 1 hour with configuration #2. The two lines in the capture spectrum at 1.778 and 6.129 MeV, normally produced by inelastic scattering, are the result of activation, $^{28}Si(n,p)^{28}Al$ and $^{16}O(n,p)^{16}N$, respectively.

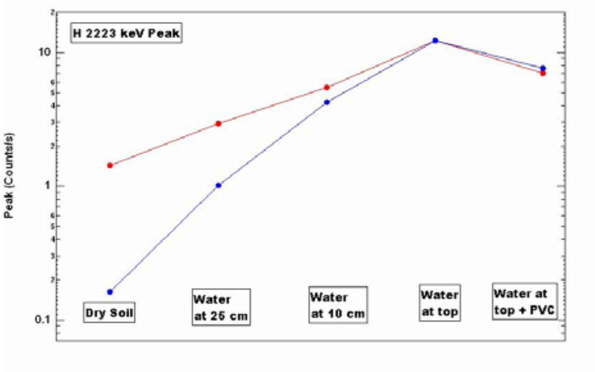

Figure 3a. Count rates for the hydrogen 2.223 MeV line, measured (red) and modeled (blue). Modeled results are normalized to agree with the measurement for configuration #4, water filled to the top of the tank.

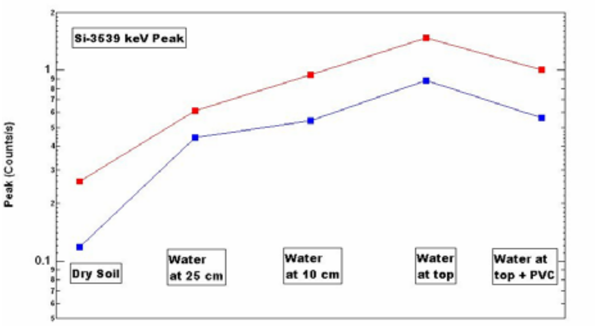

Figure 3b. Count rates for the silicon 3.539 MeV line, measured (red) and modeled (blue). Same normalization as used in 3a.